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DRY DOCKING VS. AFLOAT REPAIRS IN ISTANBUL: OPERATIONAL, COST, AND SCHEDULING COMPARISON

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1. Abstract

Ship repair strategies have emerged as a cornerstone of modern fleet management, profoundly impacting vessel availability, lifecycle costs, regulatory compliance, and commercial competitiveness. In an industry characterized by narrow operating margins, volatile freight markets[1], and increasingly stringent environmental and classification requirements, shipowners must continuously balance structural integrity, operational continuity, and cost control.

Two primary maintenance pathways dominate decision-making: scheduled dry docking and afloat repairs. While dry docking provides comprehensive access for structural renewal and statutory survey compliance, afloat repair strategies offer flexibility and reduced off-hire exposure for time-sensitive interventions. This paper presents a comprehensive comparative analysis of these two approaches in the strategic maritime hub of Istanbul, focusing on their operational efficiency, distinct cost implications, and intricate scheduling impacts.

Simultaneously, regional repair hubs have become strategically important within global shipping networks. Istanbul, situated at the crossroads of the Black Sea and Mediterranean trade routes and adjacent to the Turkish Straits, has emerged as a competitive repair cluster that combines dry-dock infrastructure, quayside facilities, and certified underwater repair services. Its geographic proximity to high-density traffic corridors enhances its suitability for both scheduled docking and rapid afloat response, creating a unique operational environment for repair strategy selection.

This study presents a structured comparative analysis between dry docking and afloat repairs within the Istanbul region. The research evaluates each method across three core dimensions: operational feasibility, cost structure (direct and indirect), and scheduling dynamics. Particular emphasis is placed on hidden cost drivers such as off-hire exposure, berth congestion, preparatory work sequencing, and traffic-related delay risks in the Turkish Straits system.

The research objectives are fourfold:
(1) to compare dry docking and afloat repairs in operational terms;
(2) to examine cost implications beyond visible repair expenditures;
(3) to analyze scheduling impacts within a congested maritime hub; and
(4) to develop a decision-support framework for technical managers and fleet superintendents.

The findings indicate that dry docking remains structurally indispensable for major steel renewal, underwater hull access, and statutory survey compliance, but carries higher schedule rigidity and off-hire risk. Conversely, afloat repairs demonstrate superior time efficiency and commercial flexibility in minor-to-moderate defect scenarios, though they are technically constrained by class requirements and environmental limitations. Within Istanbul's infrastructure ecosystem, the availability of integrated dry dock and underwater service capacity enhances strategic optionality, enabling hybrid maintenance planning models.

The paper concludes that optimal repair strategy selection is not binary but conditional, depending on damage severity, regulatory obligations, commercial pressure, and port-side operational constraints. This nuanced decision-making process necessitates a thorough understanding of the technical, economic, and logistical factors at play, particularly within a dynamic maritime environment like Istanbul. By analyzing the specific characteristics of Istanbul's port infrastructure, including prominent facilities like Ambarlı and Haydarpaşa Ports [2], this study offers practical insights for optimizing ship maintenance strategies in a critical logistical region [3].

2. Introduction

2.1 Background

Importance of Ship Maintenance in Lifecycle Asset Management

Commercial vessels represent high-capital, long-life industrial assets whose operational viability depends on structured maintenance planning. While a nominal design life of 20–25 years remains common in shipbuilding contracts, many vessels continue trading beyond 30 years when supported by systematic maintenance and repair regimes. Effective lifecycle asset management, therefore, extends beyond routine upkeep; it integrates predictive inspection, structural renewal planning, machinery overhaul cycles, and regulatory survey coordination. This holistic approach ensures sustained operational readiness, adherence to class requirements, and optimal return on investment

throughout a vessel's operational lifespan [4]. Moreover, prudent maintenance minimizes unforeseen breakdowns, which can lead to significant financial losses due to off-hire periods, emergency repairs, and potential penalties for delayed cargo delivery [5].

Ship maintenance is not merely a technical necessity but a financial determinant. Hull condition affects hydrodynamic efficiency and fuel consumption. Machinery reliability influences operational continuity and charter performance. Structural integrity directly impacts classification status and insurance coverage. As highlighted in contemporary ship repair management literature, repair scope uncertainty and scheduling variability are intrinsic to shipyard operations, reinforcing the need for structured planning frameworks. Such frameworks often incorporate advanced analytical techniques to balance maintenance costs against reliability and risk constraints, aiming for optimal solutions in complex infrastructure systems [1], [6]. Effective maintenance strategies are crucial for ensuring engine reliability, avoiding costly downtime, and maintaining safety standards in line with international regulations [7].

From a lifecycle perspective, maintenance strategy selection—particularly the choice between dry docking and afloat repairs[8]—becomes a strategic decision affecting downtime exposure, cost predictability, and risk allocation.

Regulatory Drivers

Regulatory compliance remains one of the strongest drivers shaping ship repair[9] strategies. Classification societies impose periodic survey regimes, including Annual Surveys, Intermediate Surveys, and Special Surveys (typically at five-year intervals). Certain inspections—particularly those involving underwater hull structure, sea chests, rudder systems, and tail shafts—may necessitate dry docking unless alternative inspection schemes are approved.

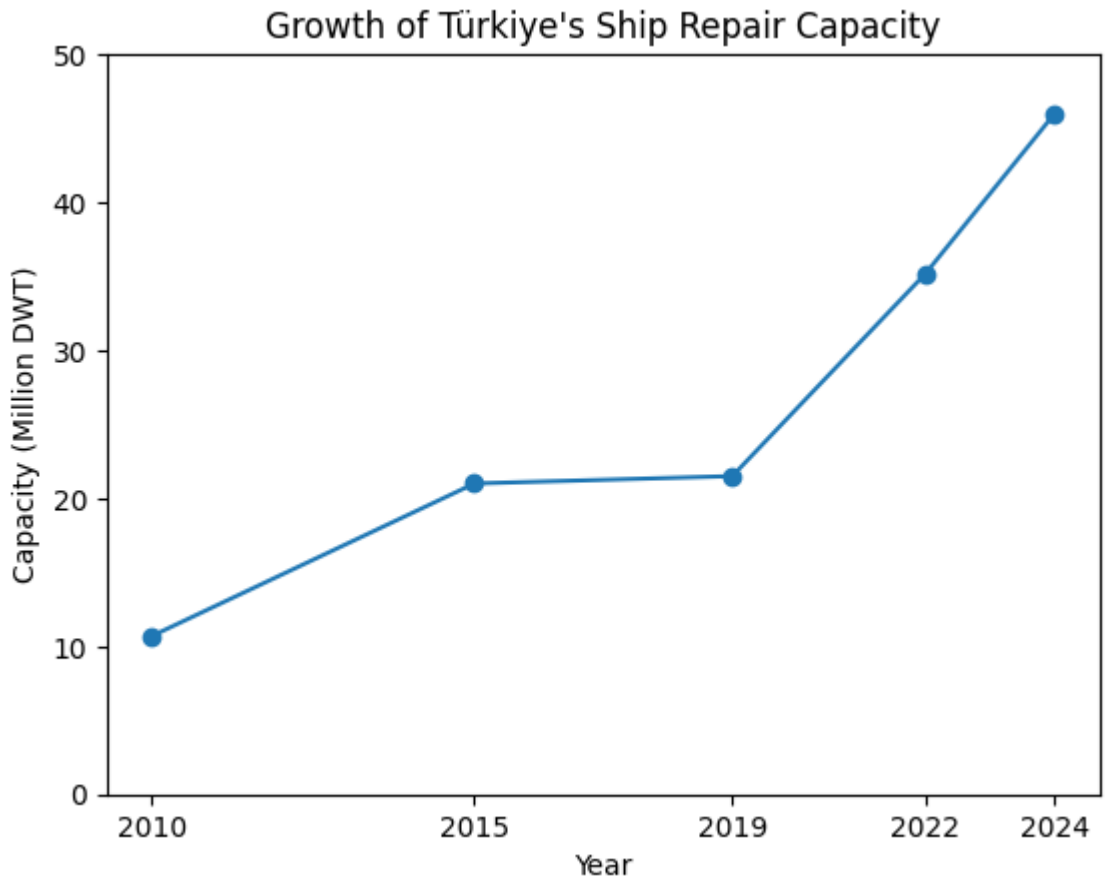
International regulatory instruments further reinforce maintenance obligations. The International Convention for the Safety of Life at Sea (SOLAS) mandates structural and safety system integrity, while the International Convention for the Prevention of Pollution from Ships (MARPOL) imposes compliance requirements affecting hull coatings, ballast water systems, and emission-related machinery components. These frameworks create mandatory repair triggers that may override purely commercial considerations. For instance, half of all reported maritime accidents in 2023 were attributed to mechanical failures, underscoring the critical link between diligent maintenance and operational safety [10].

At the same time, classification societies increasingly permit in-water surveys and continuous survey programs, allowing partial substitution of traditional dry docking under controlled conditions. This regulatory flexibility has expanded the operational role of afloat repairs, particularly in ports equipped with certified underwater service providers. However, the ultimate decision between these maintenance approaches is significantly influenced by the vessel's specific operational profile and the economic implications of each choice.

Growth of Türkiye’s Ship Repair Capacity

Over the past two decades, Türkiye has transformed into a major regional ship repair and conversion center, supported by measurable capacity expansion and infrastructure investment. In 2010, total ship repair and maintenance capacity was estimated at approximately **10.7 million DWT**. By 2015, capacity had increased to roughly **20–22 million DWT**, and by 2019 it reached around **21.5 million DWT**, effectively doubling within a decade. Growth accelerated further in the early 2020s, with reported capacity rising to approximately **35.2 million DWT by 2022**, and industry estimates indicating levels approaching **46 million DWT by 2024**, representing more than a **250% increase compared to the early 2010s**.

This expansion has been structurally supported by dock infrastructure growth in the Marmara region—primarily Tuzla and Yalova—where the number of **floating docks increased from 11 to 32** and **dry docks from 4 to 10** between 2003 and 2019. Quay lengths, heavy-lift crane capacities, and specialized workshops for steel renewal, propulsion systems, and mechanical overhauls have also expanded in parallel. Today, cumulative docking capacity in the Marmara cluster accommodates vessels ranging from small coastal ships to Panamax bulk carriers, tankers, and selected offshore units. This robust expansion underscores Türkiye's strategic intent to capture a larger share of the global ship repair market, leveraging its geographical advantage at the crossroads of major shipping lanes.



In addition to fixed dry dock expansion, Türkiye has strengthened its certified underwater repair and diving services, enabling class-approved inspections, propeller polishing, hull cleaning, and minor steel repairs to be performed afloat. This dual operational capability—integrated dry dock infrastructure combined with certified afloat intervention—enhances scheduling flexibility and reduces off-hire duration for shipowners. Collectively, the quantitative growth in DWT handling capacity, dock numbers, and service specialization has solidified Türkiye's competitive position as a high-capacity repair hub serving the Mediterranean, Black Sea, and Turkish Straits traffic corridor.

2.2 Research Problem

Shipowners and technical managers routinely face a critical decision: whether to proceed with dry dock repair or execute repairs afloat. This choice must often be made under significant constraints, including limited laytime, charter party obligations, slot availability in shipyards, and fluctuating freight markets. This complexity is exacerbated by an aging global fleet and the urgent demand for low-carbon technologies, which together intensify the need for efficient and cost-effective maintenance solutions [11]. While dry docking offers comprehensive access for extensive repairs and regulatory surveys, often for a 5-year classification cycle, afloat repairs present an appealing alternative for minor defects or urgent interventions, potentially minimizing off-hire time and associated revenue losses [12], [13]. The proliferation of digital technologies and predictive maintenance systems within shipyards also presents new opportunities for optimizing these choices, although their full integration into traditional decision-making frameworks is still evolving [14].

Dry docking provides full access for structural renewal and regulatory compliance but introduces higher off-hire exposure and schedule rigidity. Afloat repairs reduce downtime but may be technically constrained by class requirements, weather conditions, and safety considerations. Therefore, selecting the optimal repair strategy necessitates a meticulous evaluation of operational, financial, and regulatory factors to balance immediate needs with long-term asset integrity and commercial viability [15].

Decision complexity intensifies in congested trade routes such as the Turkish Straits region. Traffic density, berth availability, double banking limitations, and variable weather conditions can influence

repair feasibility and duration. Furthermore, preparatory work timing—whether performed quayside or inside dry dock—can significantly alter docking duration and associated cost exposure. Under commercial pressure, repair decisions are rarely purely technical; they are multi-dimensional trade-offs between compliance, cost, and time risk.

2.3 Research Objectives

This study aims to provide a structured comparative evaluation of dry docking and afloat repairs within the Istanbul region.

The primary objectives are:

1. **To compare dry docking and afloat repairs in operational terms**, examining technical feasibility, scope limitations, and regulatory boundaries.
2. **To evaluate cost structures and hidden cost drivers**, distinguishing between direct repair costs (dock fees, labor, materials) and indirect costs (off-hire exposure, schedule deviation, fuel inefficiency due to deferred maintenance).
3. **To analyze scheduling implications in the Istanbul region**, considering yard congestion, berth access constraints, preparatory work sequencing, and traffic-related delays.
4. **To develop a practical decision-making framework** that supports technical managers, fleet superintendents, and shipowners in selecting the optimal repair strategy based on objective criteria.

2.4 Research Questions

In order to address the research problem and objectives, this study seeks to answer the following core questions:

1. **Under what technical conditions is dry docking mandatory?**
   Specifically, which structural, mechanical, or regulatory scenarios require out-of-water access for compliance or safety reasons?
2. **When are afloat repairs operationally preferable?**
   In which cases can underwater welding, inspection, propeller treatment, or minor steel interventions provide sufficient corrective action without full docking?
3. **How do cost components differ between the two methods?**
   What are the direct and indirect cost implications, and how do hidden variables—such as off-hire duration and preparatory work constraints—affect total cost of repair?
4. **How does Istanbul's infrastructure influence repair strategy selection?**
   To what extent do dock availability, underwater service capability, traffic density, and regional trade patterns shape the economic and operational feasibility of each approach?

Through systematic analysis of these questions, the study aims to clarify the conditional logic underpinning repair strategy decisions and contribute to evidence-based fleet maintenance planning.

3. Literature Review

3.1 Dry Docking in Ship Lifecycle Management

Definition and Classification Survey Requirements

Dry docking is traditionally defined as the controlled removal of a vessel from the water to permit inspection, survey, maintenance, and structural renewal of submerged components. It constitutes a critical phase within ship lifecycle management, serving both regulatory and structural purposes. Docking operations provide full physical access to underwater hull plating, appendages, sea chests, rudder assemblies, and propulsion systems.

Classification societies mandate periodic docking in accordance with survey cycles. The Special Survey—generally conducted at five-year intervals—represents the most comprehensive structural examination within a vessel's survey regime. It typically includes close-up surveys of ballast tanks,

thickness measurements, hull steel renewal assessment, and verification of critical underwater systems. These periodic dry-dockings are crucial for managing corrosion risks to the hull girder, preventing structural degradation that could lead to catastrophic failure, economic losses, and environmental impacts [16].

While continuous survey schemes and in-water survey alternatives exist, certain structural conditions and statutory inspections still require out-of-water access. From a lifecycle perspective, dry docking functions as both a compliance checkpoint and a structural renewal window. It enables the rectification of accumulated corrosion, fatigue cracking, coating degradation, and mechanical wear that cannot be fully assessed during afloat operations.

Structural Steel Renewal and Underwater Hull Access

Structural steel renewal constitutes one of the principal justifications for dry docking. Corrosion wastage in ballast tanks, cargo holds, and underwater shell plating often becomes fully visible only after surface preparation and blasting operations. Literature emphasizes that pre-arrival repair specifications frequently underestimate the true extent of renewal requirements, as the definitive assessment can only occur once the vessel is physically docked and inspected.

Underwater hull access further enables critical operations such as tail shaft withdrawal, stern tube seal replacement, rudder bearing inspection, propeller removal, and cathodic protection system renewal. These interventions require stable working platforms, heavy lifting facilities, and yard-based engineering support.

Dock Types and Operational Constraints

Dry dock types include graving docks, floating docks, slipways, and syncrolifts. Each dock type imposes operational constraints related to size limitations, pumping capacity, structural load distribution, and stability control during docking procedures. Docking operations demand precise block positioning, trim and stability calculations, and controlled ballast management.

Operational constraints extend beyond the dock itself. Yard congestion, crane availability, workshop capacity, and steel prefabrication lead times influence total repair duration. Furthermore, preparatory work—such as hatch cover removal or tail shaft preparation—may significantly affect the effective length of dry dock occupation. Consequently, docking time cannot be evaluated purely by repair scope; it is also shaped by yard operational conditions.

3.2 Afloat Repairs and Underwater Interventions

Port Repairs and Voyage Repairs

Afloat repairs encompass maintenance activities conducted while the vessel remains in the water, either at berth or during voyage deviation stops. These interventions may include minor steelwork, machinery overhaul, electrical system repair, cargo equipment rectification, and class-approved underwater surveys.

Port repairs typically leverage quayside access and shore-based equipment, while voyage repairs prioritize minimal operational interruption. The evolution of mobile repair teams and specialized service providers has expanded the feasibility of performing corrective maintenance without dry docking.

Diver-Assisted Underwater Maintenance

Diver-assisted underwater interventions represent a critical subset of afloat repairs. These operations include propeller polishing, minor blade repair, sea chest cleaning, underwater thickness measurements, blanking of overboard valves, and limited structural patching. Certified underwater service providers operate under strict class and flag administration supervision.

The growth of in-water survey acceptance by classification societies has increased reliance on underwater inspection techniques. However, approval is conditional and subject to vessel type, age, condition, and risk assessment.

Limitations Under Class and Flag Requirements

Despite operational flexibility, afloat repairs are constrained by regulatory frameworks. Certain defects—particularly significant structural wastage, extensive cracking, tail shaft withdrawal, or rudder dismantling—cannot be completed underwater. Additionally, flag administrations and class rules may restrict underwater welding or impose post-repair inspection requirements.

Literature on ship repair management highlights that repair scope uncertainty remains higher in afloat scenarios, as limited visibility and environmental variability may restrict comprehensive assessment. Thus, while afloat repairs reduce downtime, they may not fully substitute dry docking in cases involving major structural intervention.

Safety and Environmental Considerations

Underwater operations introduce specific safety risks, including diver exposure to currents, limited visibility, entanglement hazards, and confined subsea environments. Strict diving protocols, emergency standby arrangements, and environmental compliance measures are mandatory.

Environmental considerations include pollution prevention during underwater cleaning, management of removed marine growth, and compliance with port authority regulations. These factors contribute to both operational complexity and cost variability.

3.3 Cost Estimation in Ship Repair

Labor Intensity

Ship repair is inherently labor-intensive. Structural renewal, blasting and coating, mechanical dismantling, and outfitting operations require coordinated skilled labor teams. Labor productivity varies based on yard experience, prefabrication capability, and workforce management systems.

In dry docking, labor deployment tends to peak during concentrated repair windows, while afloat repairs often utilize smaller, specialized teams for shorter durations. Producibility, encompassing aspects like accessibility and prefabrication potential, significantly impacts overall labor costs and repair timelines [17], [18]. tivity is further influenced by the specific methods, tools, and organization of production preparation, with thorough flaw detection lists being crucial for effective project planning [19].

Docking Fees and Yard Overheads

Dry docking introduces fixed and semi-fixed cost elements, including dock rental fees, pumping charges, crane usage, scaffolding, staging, and yard overhead allocation. These costs are typically independent of the precise repair scope and are time-dependent; extended docking duration proportionally increases total expense.

Yard overhead structures—administration, supervision, safety compliance, utilities—are embedded within repair quotations. Literature emphasizes that yard load factor and production scheduling conditions influence final cost outcomes.

Opportunity Cost of Off-Hire

Beyond visible repair invoices, off-hire exposure represents a major indirect cost. During dry docking, vessels are generally withdrawn from commercial service, resulting in lost charter revenue. In high freight markets, opportunity cost may exceed direct repair expenditures.

Afloat repairs, by contrast, may be conducted alongside cargo operations or within short port stays, significantly reducing revenue loss. However, incomplete or temporary repairs may generate deferred maintenance costs or fuel inefficiency penalties. Accurate forecasting of project duration and cost estimation at the bidding or early planning stages is challenging in the shipbuilding and offshore industries due to the custom-order nature of projects, where historical data may be limited or require significant adaptation [20].

Production Scheduling Variability

Production scheduling variability is a recurrent theme in ship repair literature. Repair duration depends not only on scope but also on yard congestion, material availability, and sequence coordination. Deviations from planned schedules can escalate labor cost, extend dock occupation, and amplify indirect financial exposure. Effective cost management in ship repair projects therefore

necessitates rigorous earned value management to monitor progress against budget and schedule, identifying potential overruns early [21].

Cost estimation therefore requires integration of operational and scheduling risk factors rather than reliance on static price quotations. A detailed cost breakdown typically includes material, labor, and overhead components, with profit calculated as a percentage of these combined costs [22]. Factors influencing ship repair costs include vessel type, the nature and organization of repairs, raw material prices, and the qualifications of the personnel involved [21].

3.4 Scheduling Theory in Ship Repair Operations

Critical Path in Dry Docking

Dry docking functions as a tightly sequenced production system. Critical path analysis identifies activities that directly determine total docking duration, such as hull blasting, steel renewal completion, tail shaft reinstallation, and survey clearance. Delays in these tasks propagate across subsequent operations.

Literature on dry dock management underscores the importance of sequencing efficiency and resource allocation in minimizing occupation time. Sophisticated planning tools, often leveraging methodologies like the Critical Path Method, are employed to optimize these complex interdependencies and mitigate potential delays in large-scale repair projects [23], [24].

Preparatory Work Impact

Preparatory work significantly affects dry dock time. If steel prefabrication, hatch cover removal, and machinery pre-dismantling are conducted prior to docking, overall dock occupation may be reduced. Conversely, absence of preparatory work shifts these tasks into the docking window, extending total duration.

This dynamic illustrates that dry dock duration is not solely determined by repair complexity but also by logistical planning and berth availability.

Berth Congestion and Yard Load Factor

Shipyards operate within capacity constraints. High yard load factors increase competition for cranes, workshops, and labor resources. Berth congestion may delay preparatory activities, indirectly increasing docking time.

In regions with dense maritime traffic, such as the Turkish Straits, berth allocation and scheduling precision become critical variables influencing repair timing.

Time-Risk Exposure in Congested Waterways

Congested waterways introduce additional scheduling uncertainty. Traffic density, pilot availability, port authority restrictions, and weather conditions can delay vessel arrival or departure. In high-traffic regions, these variables elevate time-risk exposure for both dry docking and afloat repairs.

Consequently, repair strategy selection must incorporate not only technical feasibility and cost estimation but also scheduling resilience within region-specific operational environments.

4. Methodology

4.1 Research Design

Comparative Analytical Framework

This study adopts a comparative analytical research design to evaluate dry docking and afloat repairs as alternative ship maintenance strategies within the Istanbul region. The research framework is structured to enable systematic comparison across operational, economic, and scheduling dimensions.

Rather than treating dry docking and afloat repairs as isolated technical activities, the study positions them within a multi-variable decision environment. The framework integrates lifecycle maintenance theory, cost estimation principles, and scheduling analysis to assess performance under realistic

operational constraints. Each repair method is evaluated against identical comparative criteria to ensure methodological consistency.

The comparative model operates on three levels:

1. **Technical-operational level** – assessing feasibility, scope limitations, regulatory compliance, and infrastructure constraints.
2. **Cost-structural level** – distinguishing between direct repair costs and indirect economic exposure.
3. **Scheduling-risk level** – evaluating duration, sequencing sensitivity, congestion impact, and time-risk exposure.

This layered structure allows for cross-dimensional evaluation and identification of conditional advantages rather than binary superiority.

Qualitative + Cost-Structural Evaluation

The research employs a mixed analytical approach combining qualitative assessment and cost-structural evaluation.

The qualitative component examines regulatory requirements, operational constraints, class limitations, yard capacity conditions, and underwater intervention feasibility. This aspect captures contextual and structural influences that cannot be reduced to numerical variables.

The cost-structural component disaggregates repair-related expenditures into:

- Fixed and variable direct costs
- Time-dependent yard costs
- Revenue loss exposure
- Secondary performance impacts (e.g., fuel inefficiency due to deferred hull treatment)

By combining descriptive operational analysis with structured cost modeling logic, the research maintains both technical rigor and practical applicability.

4.2 Data Sources

The study relies on multiple data categories to ensure triangulation and analytical robustness.

Industry Reports

Industry publications, maritime economic analyses, and fleet maintenance studies provide macro-level insight into global ship repair trends, off-hire economics, and lifecycle maintenance strategies. These reports support contextualization of Istanbul’s role within broader regional repair markets.

Shipyard Operational Practices

Operational characteristics of dry docks and quayside facilities are examined through documented shipyard practices, including:

- Dock occupation sequencing
- Preparatory work procedures
- Steel prefabrication processes
- Labor allocation models
- Yard load factor dynamics

These operational patterns inform scheduling analysis and production variability considerations.

Repair Case Comparisons

Representative repair scenarios are constructed to enable structured comparison. These scenarios include:

- Minor hull damage
- Major structural steel renewal
- Propeller repair
- Stern seal intervention

Each case is evaluated under both dry dock and afloat conditions to identify differences in cost structure, duration, and risk exposure.

Scenario-based comparison supports break-even modeling logic and conditional strategy assessment.

Regulatory Frameworks

International maritime conventions (SOLAS, MARPOL), classification society rules, and flag administration requirements are incorporated to define mandatory repair thresholds and compliance triggers.

Survey cycles, underwater inspection eligibility, and restrictions on in-water welding are analyzed to determine regulatory feasibility boundaries. This ensures that operational preference is assessed within legal and class-approved constraints.

4.3 Comparative Criteria

To maintain methodological clarity, both repair strategies are evaluated against standardized comparative criteria.

1. Technical Feasibility

This criterion examines whether the required repair scope can be physically and legally executed under each method. It includes:

- Structural renewal requirements
- Underwater hull access needs
- Machinery dismantling scope
- Class and flag compliance limitations
- Environmental and weather constraints

Dry docking is expected to score higher in major structural feasibility, while afloat repairs may demonstrate advantage in minor corrective interventions.

2. Direct Costs

Direct costs encompass identifiable repair expenditures, including:

- Docking fees
- Yard equipment usage
- Labor charges
- Steel and coating materials
- Diving team mobilization (for afloat repairs)

Cost comparison focuses not only on nominal values but also on cost dependency on time duration.

3. Indirect Costs

Indirect costs represent economic exposures beyond invoice values. These include:

- Off-hire revenue loss
- Charter party penalties
- Schedule deviation impact
- Fuel penalties from postponed hull maintenance
- Risk of repeated intervention if repair is temporary

Indirect cost evaluation is critical for understanding total economic impact rather than surface repair cost.

4. Time Efficiency

Time efficiency measures:

- Total repair duration
- Preparatory work impact
- Mobilization speed
- Deviation distance
- Yard congestion sensitivity

Afloat repairs are hypothesized to provide shorter immediate duration in minor defect cases, whereas dry docking may deliver greater efficiency in bundled major repairs.

5. Risk Exposure

Risk exposure evaluates:

- Structural safety risk
- Regulatory non-compliance risk
- Scheduling delay risk
- Weather-related uncertainty
- Operational congestion impact

This criterion integrates both technical and commercial risk dimensions. Producement and material costs are also integral to the comprehensive financial assessment, as the selection of coatings, for example, directly impacts lifecycle performance and subsequent maintenance outlays [25].

5. Operational Comparison

5.1 Scope of Work Feasibility

Operational feasibility is the primary differentiating factor between dry docking and afloat repairs. The decision to select one method over the other is fundamentally governed by the technical scope of work required.

Dry Docking

Dry docking provides unrestricted physical access to the vessel's underwater body and associated appendages. Once the vessel is safely landed on blocks and water is pumped out, the hull, rudder, propeller, sea chests, and stern arrangements become fully accessible for inspection, measurement, and structural intervention. This comprehensive access facilitates extensive hull cleaning, grit blasting, coating application, and major structural renewals, which are often mandated during special surveys [26], [27].

Full Hull Access
Dry docking enables complete visual and physical inspection of shell plating, bilge keels, thruster tunnels, sea chest gratings, and sacrificial anodes. Surface preparation (grit blasting or ultra-high-pressure water jetting) allows accurate assessment of corrosion wastage and coating degradation.

Thickness measurements can be conducted systematically across exposed steel areas. This unhindered access is crucial for extensive steel renewal, particularly in aging vessels where localized repairs might not suffice [17]. Such thorough access also supports comprehensive propeller polishing, rudder stock inspections, and stern tube seal replacements, addressing critical components not easily accessible otherwise [28], [29].

Major Structural Steel Renewal
Substantial structural interventions—such as renewal of bottom plating, doubler removal, frame replacement, or extensive ballast tank steelwork—are feasible only in dry dock. Large-scale steel cutting, prefabrication, alignment, and welding require stable working platforms, scaffolding systems, and crane support. As documented in ship repair management literature, actual steel renewal quantities often exceed pre-arrival estimates once surfaces are fully exposed. This comprehensive access ensures that all routine and occasional maintenance, including critical tasks like tail shaft withdrawal and anchor chain calibration, can be executed thoroughly and efficiently [17]. Furthermore, dry docking allows for the rigorous application and assessment of fouling control coatings, which is a critical factor in a vessel's long-term performance and regulatory compliance [30].

Tail Shaft Withdrawal
Withdrawal of the tail shaft for survey and inspection remains a classic dry docking activity. The procedure requires stern area access, alignment control, and often heavy lifting capacity. It is structurally and practically infeasible underwater. Similarly, comprehensive inspection and repair of steering gear components, including rudder stock and pintle examinations, necessitate dry dock conditions to ensure proper alignment and structural integrity [17].

Rudder and Propeller Removal
Major repairs involving rudder stock extraction, bearing renewal, propeller removal, or blade replacement necessitate dry docking. These operations involve precision alignment, machining, and controlled handling, which cannot be safely executed afloat.

In summary, dry docking accommodates full-scope structural and mechanical intervention without physical limitation, subject primarily to yard capability and dock size constraints. Conversely, afloat repairs, while offering flexibility, are inherently limited by the persistent immersion of the hull, necessitating specialized underwater techniques and equipment.

Afloat Repairs

Afloat repairs are inherently limited by underwater access conditions and regulatory restrictions. However, they provide flexibility in addressing localized or minor defects. These repairs are often employed for routine maintenance tasks, minor hull damage, or urgent interventions that do not necessitate full dewatering or extensive structural work.

Underwater Welding and Temporary Steel Patches
Certified underwater welding may be employed for limited crack arrest or localized shell damage repair. Such repairs are typically temporary or conditionally approved pending permanent renewal at the next docking. Structural load-bearing areas are generally excluded unless specifically authorized by class.

Propeller Polishing and Minor Blade Repair
Propeller polishing is one of the most common afloat interventions. Diver-assisted polishing improves hydrodynamic efficiency and reduces fuel consumption without removing the vessel from service. Minor blade edge dressing or localized repair may also be feasible underwater, provided deformation is limited.

Sea Chest Cleaning
Marine growth accumulation in sea chests can restrict cooling water intake. Diver cleaning restores operational efficiency without docking, offering rapid turnaround. However, the effectiveness and longevity of these afloat repairs are critically dependent on the prevailing environmental conditions, including water clarity, currents, and weather, which can significantly impact diver operations and the quality of the repair work.

Limited Structural Intervention
Afloat structural work is confined to small-scale, non-critical areas. Extensive plating renewal, structural reinforcement, or appendage removal is beyond operational feasibility due to stability, safety, and inspection limitations.

Overall, afloat repairs are best suited to corrective maintenance, performance optimization, and temporary defect management rather than comprehensive structural rehabilitation. They offer significant advantages in terms of reduced off-hire time and lower direct costs, but these benefits must be weighed against the inherent limitations in scope and the potential for regulatory constraints [31].

5.2 Technical Constraints

Beyond scope feasibility, each repair method is influenced by technical constraints that may restrict operational execution.

Stability Considerations in Dry Dock

Docking a vessel requires detailed stability and load distribution calculations. Improper block arrangement or trim misalignment can induce structural stress concentrations. Dry dock procedures demand controlled ballast management, weight estimation, and sequential support engagement.

Additionally, docking availability may be limited by vessel dimensions, displacement, and dock capacity. Extremely large vessels may face slot scarcity or size restrictions. For afloat repairs, however, the vessel's inherent stability remains largely unaffected, as it continues to operate in its natural element, albeit with localized interventions [32].

Weather and Current Limitations in Afloat Repairs

Underwater interventions are sensitive to environmental conditions. Strong currents, poor visibility, adverse weather, or swell can suspend diving operations. In high-traffic waterways such as the Turkish Straits, vessel movement and wash effects further complicate underwater stability.

Operational windows for afloat repairs may therefore be narrower and subject to abrupt interruption. This introduces scheduling uncertainty absent in controlled dry dock environments.

Class Attendance Requirements

Classification society attendance is mandatory for many repair activities. For major structural renewals or statutory surveys, surveyors must witness work stages and approve completion. While some underwater surveys are permitted, class rules often limit in-water substitution for specific inspection items.

Failure to meet attendance requirements may invalidate repair certification. Therefore, technical feasibility is partially dictated by regulatory approval rather than physical capability alone.

5.3 Safety and Environmental Factors

Safety and environmental compliance are central to operational comparison.

Confined Space Operations

Dry docking frequently involves confined space entry into ballast tanks, double bottoms, and void spaces. These operations require gas freeing, atmosphere testing, ventilation systems, and entry permits. Steel renewal and coating works introduce additional hazards related to hot work and solvent exposure.

Despite these risks, dry dock conditions provide controlled access, stable footing, and fixed scaffolding, enhancing structural work safety when properly managed.

Diving Safety Protocols

Afloat repairs rely on professional diving teams operating under strict safety standards. Diving operations must include standby divers, communication systems, emergency recovery plans, and decompression management.

Risks include entrapment, reduced visibility, equipment malfunction, and vessel movement. Diving safety is highly dependent on environmental stability and coordination with port authorities.

Waste Handling Compliance

Dry docking generates significant waste streams, including blasting grit, paint residues, steel scrap, and oily sludge. Shipyards must manage these materials in accordance with environmental regulations.

Underwater cleaning operations also require compliance with local port environmental standards to prevent uncontrolled marine growth discharge or pollutant release.

Emission Considerations

Dry dock operations may involve extended auxiliary engine use, crane operation, and heavy equipment deployment. Afloat repairs, while shorter in duration, may involve auxiliary machinery running during diving operations.

From an environmental perspective, propeller polishing and hull cleaning afloat can reduce fuel consumption and emissions over subsequent voyages, contributing to lifecycle sustainability improvements. However, the environmental benefits of afloat repairs are contingent upon the rigorous application of approved cleaning techniques and the proper containment and disposal of removed fouling, ensuring that no harmful substances are released into the marine environment [33].

6. Cost Structure Analysis

Cost evaluation in ship repair extends beyond visible invoice values. A comprehensive assessment requires separation of direct operational expenditures from indirect commercial exposure. This section disaggregates cost components for dry docking and afloat repairs and introduces scenario-based comparative modeling.

6.1 Direct Cost Components

Dry Docking

Dry docking is characterized by a combination of fixed time-dependent costs and variable scope-dependent costs.

Docking Fees

Docking fees represent a primary fixed cost component. These charges are generally calculated based on:

- Vessel dimensions (LOA, beam, displacement)
- Dock occupation duration (days)
- Pumping and docking services
- Shore services (electricity, freshwater, compressed air)

Docking fees are time-sensitive; each additional day in dock directly increases total cost. Therefore, schedule extension carries immediate financial impact. Additional costs are incurred for services such as crane usage, electricity, fresh water, and waste disposal, all of which contribute to the overall expense of a dry-docking period. Variable costs arise from the actual repair work performed, including material, labor, and specialized subcontractor services, such as steel renewals or machinery overhauls. The economic-environmental impact of such expenditures can be substantial, necessitating a comprehensive framework for decision support in vessel maintenance [34].

Crane and Yard Equipment

Major steel renewal and appendage removal require heavy lifting equipment, floating cranes, dockside cranes, forklifts, scaffolding, staging systems, and access platforms. These equipment charges may be billed on daily or hourly rates. The utilization of such specialized equipment significantly contributes to the overall operational expenditure of dry-docking projects. Furthermore, the cost of these assets includes not only their direct rental or usage fees but also the overheads associated with their maintenance and deployment.

In high-capacity yards, crane availability and internal resource allocation influence not only cost but also sequencing efficiency.

Steel Renewal Materials

Structural renewal cost is directly linked to:

- Quantity of steel replaced (measured in metric tons)
- Prefabrication labor
- Cutting and welding consumables
- Non-destructive testing (NDT)
- Surface preparation and primer application

As noted in ship repair management literature, steel renewal quantities frequently increase after detailed inspection in dock, leading to scope growth and budget escalation. This phenomenon highlights the critical need for robust initial surveys and flexible budgeting to mitigate unforeseen expenses during dry docking periods.

Coating Systems

Coating systems constitute a significant expense in dry docking. Costs include:

- Surface preparation (blasting or hydro-jetting)
- Primer and topcoat application
- Specialized antifouling paints
- Labor-intensive staging and curing time

Coating quality directly affects fuel performance and lifecycle corrosion resistance, creating long-term financial implications beyond immediate expenditure.

Afloat Repairs

Afloat repair cost structure differs in composition and time profile.

Diving Team Mobilization

Diving operations require certified personnel, support vessels (if applicable), communication systems, and standby safety arrangements. Mobilization charges include transportation, equipment setup, and administrative clearance with port authorities.

Mobilization cost may represent a significant portion of total expense, especially for short-duration interventions.

Specialized Equipment

Underwater welding machines, hydraulic tools, subsea cameras, thickness measurement instruments, and cleaning systems are specialized assets. Equipment rental and maintenance costs are typically embedded within service quotations.

Short-Duration Manpower Deployment

Afloat repairs are generally completed within compressed timeframes. Manpower is deployed intensively over short operational windows. While daily cost rates may be high, total duration is limited, often reducing aggregate expenditure compared to extended docking.

In summary, direct costs for dry docking tend to be higher in absolute terms due to facility usage and extended duration, whereas afloat repairs concentrate cost into specialized, short-term service mobilization.

6.2 Indirect Cost Components

Indirect costs often exceed direct repair expenditures and strongly influence strategic decision-making.

Off-Hire Time

Off-hire represents lost revenue during periods when a vessel cannot trade. In dry docking, vessels are typically withdrawn from service entirely. If daily charter income is significant, even minor schedule extension results in substantial financial impact.

Afloat repairs may be conducted during cargo operations or short port stays, minimizing or eliminating off-hire exposure.

Charter Party Penalties

Under time charter agreements, failure to meet delivery windows or operational availability commitments may trigger penalties or claims. Extended dry dock duration or unforeseen steel renewal expansion can create contractual liabilities.

Afloat repairs reduce prolonged withdrawal risk but may carry residual risk if temporary repairs necessitate future corrective docking.

Schedule Deviation

Deviation cost includes:

- Additional fuel consumption
- Pilotage and port fees
- Tug assistance
- Agency costs

In Istanbul's high-traffic maritime environment, deviation to a dry dock facility must be weighed against voyage continuity and transit timing.

Fuel Inefficiency Due to Deferred Repair

Deferring hull cleaning or propeller polishing can increase fuel consumption. Biofouling accumulation raises hydrodynamic resistance, resulting in measurable bunker penalties.

Afloat propeller polishing can deliver rapid efficiency gains, offsetting service cost through fuel savings within a short payback period.

Indirect cost evaluation therefore requires integration of commercial revenue models, fuel economics, and charter risk exposure.

6.3 Comparative Cost Modeling

To illustrate structural differences, this study introduces scenario-based cost modeling.

Scenario 1: Minor Hull Damage Case

Condition:
Localized bottom shell dent with minor coating breakdown.

Dry Dock Option:

- Docking fees
- Surface preparation and steel cropping
- Coating renewal
- Off-hire exposure

Total cost structure includes significant fixed docking charges disproportionate to repair size.

Afloat Option:

- Diver inspection
- Underwater welding patch (if class-approved)
- Short-duration manpower

In this scenario, afloat repair typically demonstrates cost advantage due to elimination of docking fees and minimized revenue loss. However, approval depends on defect classification and structural criticality.

Scenario 2: Major Structural Renewal Case

Condition:
Extensive corrosion wastage in ballast tank bottom plating exceeding class allowable limits.

Dry Dock Option:

- Full surface preparation
- Structural renewal in controlled environment
- Coating system renewal
- Class attendance and certification

Although direct cost is high, structural integrity is permanently restored.

Afloat Option:
Not technically feasible for permanent structural renewal. Temporary patches may be rejected by class.

In this scenario, dry docking becomes mandatory despite higher direct and indirect cost, as regulatory and structural constraints override commercial considerations.

Break-Even Analysis Framework

A structured break-even model compares:

TotalCost=DirectRepairCost+IndirectCommercialExposureTotal Cost = Direct Repair Cost + Indirect Commercial ExposureTotalCost=DirectRepairCost+IndirectCommercialExposure

For dry docking:

TCDD=(DockFees+Labor+Materials+Equipment)+(Off−Hire×DailyRevenue)TC_{DD} = (Dock Fees + Labor + Materials + Equipment) + (Off-Hire × Daily Revenue)TCDD =(DockFees+Labor+Materials+Equipment)+(Off−Hire×DailyRevenue)

For afloat repairs:

TCAF=(Mobilization+SpecializedServices)+(LimitedOff−HireorDeviationCost)TC_{AF} = (Mobilization + Specialized Services) + (Limited Off-Hire or Deviation Cost)TCAF =(Mobilization+SpecializedServices)+(LimitedOff−HireorDeviationCost)

Break-even occurs when:

TCDD=TCAFTC_{DD} = TC_{AF}TCDD=TCAF

If indirect cost (off-hire) dominates total exposure, afloat repair becomes economically preferable for minor or moderate defects. Conversely, if defect severity requires structural permanence and regulatory compliance, dry docking remains economically justified despite higher nominal expenditure.

7. Scheduling Impact Analysis

Scheduling impact is a decisive variable in ship repair strategy selection. While cost structure determines financial exposure, scheduling determines commercial continuity and risk propagation. In high-density maritime regions such as Istanbul and the Turkish Straits system, time-related variables frequently outweigh nominal repair cost considerations.

7.1 Dry Dock Scheduling Dynamics

Slot Availability in Istanbul Shipyards

Dry docking requires prior reservation of dock space. In Istanbul’s Tuzla and Yalova clusters, dock capacity is finite and demand fluctuates seasonally. Scheduled Special Surveys, emergency dockings, and conversion projects compete for limited dock slots.

Slot availability introduces planning rigidity. If a docking window is missed, the next available slot may be delayed by weeks, particularly during peak repair seasons. This constraint directly influences repair timing and may force alignment with trade cycle pauses rather than purely technical convenience.

Yard Congestion Impact

Even after securing a dock slot, yard congestion affects operational execution. High yard load factor reduces crane availability, increases labor competition, and extends response time for prefabrication and material supply. Production scheduling variability, as documented in ship repair management research

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, demonstrates that identical repair scopes may result in different docking durations depending on yard workload at the time.

Congestion can:

- Delay preparatory works
- Extend steel prefabrication cycles
- Create bottlenecks in blasting and coating stages
- Prolong critical path activities

Thus, docking duration is not solely a function of repair complexity but also of yard operational environment.

Preparatory Work Before Docking

Preparatory work significantly affects effective dock occupation time. Activities such as:

- Hatch cover removal
- Machinery pre-dismantling
- Steel plate prefabrication
- Staging preparation

can be completed while the vessel is alongside a quay before entering the dock. If these tasks are completed in advance, the critical path duration inside the dock is reduced.

Conversely, if the vessel proceeds directly into dry dock without preparatory work, these tasks extend dock time. Literature illustrates how the absence of pre-docking preparation increases total docking duration despite an identical repair scope. Therefore, scheduling optimization depends on integrated berth planning and dock sequencing.

Critical Repair Sequencing

Dry docking operates under a tightly controlled sequence. Certain activities determine total docking duration:

- Surface preparation and steel renewal completion
- Tail shaft reinstallation
- Coating curing periods
- Class survey clearance

Any delay in these critical path items extends total docking time. Parallel work planning and resource coordination are therefore essential for schedule control.

In summary, dry dock scheduling is highly structured but exposed to slot dependency and yard congestion risk.

7.2 Afloat Repair Time Efficiency

Rapid Mobilization Advantage

Afloat repairs benefit from rapid mobilization capability. Certified diving teams and specialized service providers can often mobilize within short notice, subject to port authority approval. This agility minimizes disruption to the vessel's trading schedule, a significant advantage particularly for vessels operating on tight schedules or in areas with limited dry docking facilities. This rapid response capability makes afloat repairs particularly attractive for urgent, localized defects that do not necessitate extensive hull exposure or structural overhauls.

Unlike dry docking, afloat repairs do not require long-term slot reservation. Mobilization flexibility reduces planning lead time and enhances responsiveness to emergent defects. This minimizes off-hire periods, allowing vessels to maintain their commercial operations with minimal interruption [35].

Minimal Deviation from Trade Route

Istanbul’s location along a major international transit corridor provides strategic advantage. Vessels transiting between the Black Sea and Mediterranean can conduct afloat repairs without significant geographical deviation.

Minimal deviation reduces:

- Additional fuel cost
- Port stay extension
- Charter disruption

From a scheduling perspective, afloat repair aligns more closely with voyage continuity. This avoids the extensive logistical planning and coordination typically associated with dry docking, which often requires rerouting the vessel to a specific shipyard [36].

Short-Term Corrective Intervention

Afloat repairs are typically executed within compressed operational windows—often during cargo operations or short port calls. This minimizes off-hire exposure and schedule disruption.

However, time efficiency is conditional on:

- Favorable weather and current conditions
- Availability of certified divers
- Port authority clearance

Although rapid in execution, afloat repairs remain vulnerable to environmental interruption.

Overall, afloat repair scheduling demonstrates higher flexibility and shorter immediate duration but greater environmental sensitivity.

7.3 Risk of Delay in the Turkish Straits Region

The Turkish Straits represent one of the most operationally complex maritime corridors globally. Scheduling decisions must account for regional traffic and environmental variables. The high volume of maritime traffic through the Bosphorus and Dardanelles, combined with strong currents and unpredictable weather patterns, significantly impacts repair timelines and logistical coordination [37]. The angular windings of the Bosphorus necessitate frequent course alterations, further complicating safe maneuverability and potentially impacting repair schedules if specific windows for safe operations are missed [38].

Traffic Density Implications

The Bosphorus and Dardanelles handle substantial annual vessel traffic. Transit sequencing, pilot availability, and Traffic Separation Scheme regulations may delay entry or exit windows.

For dry docking, delayed arrival at dock due to transit congestion may shift docking commencement. For afloat repairs, underwater operations must coordinate with traffic movement and port authority restrictions.

High traffic density increases schedule uncertainty and time-risk exposure.

Port Berth Limitations

Berth availability influences both preparatory works and afloat repair feasibility. Limited quay length or competing vessel demand may prevent adequate working conditions.

Berth allocation delays may:

- Postpone preparatory work before docking
- Restrict diver access
- Increase waiting time

These constraints directly affect repair timeline reliability.

Double Banking Constraints

In congested ports, vessels may be berthed alongside another ship (double banking). While operationally efficient for cargo handling, double banking restricts shore crane access and may limit underwater service accessibility.

As illustrated in ship repair case discussions

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, absence of adequate access during preparatory phases can extend subsequent docking duration. Double banking therefore indirectly influences both dry dock and afloat repair scheduling efficiency.

Weather Exposure Factors

Strong currents, wind conditions, and visibility fluctuations in the Istanbul region impact underwater operations. Adverse weather may suspend diving activities, extending repair time beyond planned duration.

Dry docking is less directly exposed to marine weather once inside the dock, although external weather conditions can delay vessel arrival or departure.

Comparative Scheduling Insight

Dry docking offers controlled execution once commenced but requires advance planning and is exposed to slot rigidity and yard congestion. Afloat repairs provide higher short-term flexibility and reduced deviation but are more sensitive to environmental and traffic-related disruptions.

In the Istanbul and Turkish Straits context, scheduling impact becomes a dynamic variable shaped by infrastructure capacity, traffic density, berth management, and weather variability. Repair strategy selection must therefore integrate not only technical and cost considerations but also regional time-risk exposure.

8. Strategic Implications for Shipowners

Strategic maintenance planning in modern fleet management requires balancing structural integrity, regulatory compliance, commercial continuity, and lifecycle cost optimization. The comparative findings of this study indicate that dry docking and afloat repairs should not be viewed as competing alternatives in isolation but as complementary tools within an integrated maintenance strategy.

For shipowners and technical managers operating in high-density regions such as Istanbul and the Turkish Straits, strategic alignment of repair method with operational context becomes critical. This section translates analytical findings into decision-support guidance.

8.1 Decision-Making Matrix

The following matrix synthesizes comparative performance characteristics identified throughout the study:

Factor	Dry Dock	Afloat Repair
Structural Damage	✓ Suitable for major structural renewal	Limited to minor/localized defects
Off-Hire Risk	High (full withdrawal from service)	Low (short-duration intervention)
Cost Predictability	Moderate (subject to scope growth after inspection)	Variable (mobilization and environmental uncertainty)
Schedule Flexibility	Low (slot-dependent, fixed duration)	High (rapid mobilization, short execution window)
Regulatory Requirement	Mandatory for Special Survey and major structural work	Conditional (subject to class approval)

Interpretation

Structural Damage
Dry docking remains indispensable where extensive steel renewal, appendage removal, or statutory inspection is required. Afloat repairs are structurally limited to minor interventions and temporary rectification.

Off-Hire Risk
Dry docking concentrates downtime within a defined window but exposes owners to revenue loss. Afloat repairs minimize commercial interruption, particularly for vessels operating under tight charter schedules.

Cost Predictability
Dry dock cost predictability is moderate because actual steel renewal quantities often exceed initial estimates once surfaces are exposed

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. Afloat repair cost variability stems from environmental interruption and conditional class approval.

Schedule Flexibility
Dock slot availability and yard congestion constrain dry docking flexibility. In contrast, afloat repair offers responsiveness, particularly in transit corridors such as Istanbul.

Regulatory Requirement
Certain statutory surveys mandate dry docking. Afloat repairs remain permissible only when class and flag administrations authorize in-water substitution.

The matrix reinforces that optimal selection depends on defect severity, charter exposure, and regulatory timing.

8.2 Operational Strategy Recommendations

Based on comparative findings, several strategic approaches emerge for shipowners.

Hybrid Maintenance Planning

Rather than deferring all maintenance to scheduled dockings, shipowners should adopt a hybrid model combining:

- Periodic dry docking for structural integrity and statutory compliance
- Targeted afloat interventions for performance optimization and minor defect correction

This approach reduces docking scope accumulation and spreads maintenance workload across the trading cycle.

Predictive Maintenance Integration

Integration of condition monitoring systems, hull performance analytics, and machinery diagnostics enables earlier detection of emerging defects. Predictive maintenance reduces emergency docking risk and supports planned intervention during commercially favorable windows.

For example:

- Monitoring fuel consumption trends to identify hull fouling
- Conducting underwater inspection following grounding suspicion
- Scheduling propeller polishing before efficiency degradation becomes economically significant

Predictive systems reduce reactive repair decisions driven by urgent failures.

Use of Underwater Inspection Before Docking

Pre-docking underwater inspection provides critical scope validation. Diver-assisted inspection prior to scheduled docking allows:

- Accurate steel renewal estimation
- Early identification of appendage damage
- Optimized material procurement and prefabrication planning

This practice mitigates scope growth risk and enhances docking schedule reliability.

Underwater inspection also supports decision-making regarding whether docking can be postponed or must proceed immediately.

Strategic Docking During Trade Cycle Pauses

Optimal docking timing aligns with commercial cycle troughs, seasonal demand reduction, or charter transition periods. By synchronizing docking with natural revenue gaps, owners reduce effective off-hire impact.

In the Istanbul region, proximity to the Turkish Straits enables docking without excessive geographic deviation. Owners can incorporate docking plans into voyage routing strategy rather than treating docking as a separate logistical event.

Strategic Insight

The central strategic implication is that repair method selection should be framed as a risk-optimized allocation problem rather than a purely technical decision. Dry docking provides structural certainty and regulatory compliance; afloat repair provides operational agility.

For shipowners operating in high-traffic corridors such as the Turkish Straits, the ability to leverage both models effectively enhances fleet resilience, cost control, and schedule stability. The competitive advantage lies not in choosing one method exclusively, but in orchestrating both within a structured, data-informed maintenance framework.

10. Discussion

Istanbul’s Competitive Advantage as a Repair Hub

The findings of this study confirm that Istanbul occupies a structurally advantageous position within regional ship repair markets. Its geographic location at the junction of the Black Sea and Mediterranean trade routes significantly reduces deviation cost for transiting vessels. This proximity transforms repair planning from a geographically disruptive activity into an integrated voyage decision.

Beyond location, Istanbul’s repair ecosystem combines:

- Multiple dry dock facilities in Tuzla and Yalova
- Quayside repair capability
- Certified underwater inspection and diving services

  Underwater and Diving Services …
- Established classification society presence
- Access to regional fabrication and engineering supply chains

This infrastructure diversity supports both high-capacity dry docking and rapid afloat intervention. Unlike repair clusters that specialize in one model exclusively, Istanbul provides dual-capability flexibility. This enhances strategic optionality for shipowners managing vessels under dynamic charter conditions. This integrated capacity allows for optimized maintenance scheduling that minimizes off-hire periods and aligns with operational requirements, including the ability to implement digital strategies for enhanced efficiency and reduced downtime [39].

Furthermore, yard experience in handling varied vessel types—bulk carriers, tankers, LPG vessels, and container ships—contributes to production familiarity and technical reliability. The ability to integrate preparatory works alongside docking operations also supports scheduling efficiency. This multifaceted environment fosters a competitive market, which can translate into more favorable pricing and service delivery for shipowners [40]. The strategic adoption of digital solutions, such as AI-powered predictive maintenance and real-time sensor integration, further enhances Istanbul's appeal by enabling data-driven maintenance strategies that optimize project management and operational efficiency [14], [39].

In operational terms, Istanbul's competitive advantage is not limited to cost competitiveness; it lies in its structural flexibility.

Increasing Preference for Afloat Repairs in Time-Sensitive Operations

The analysis indicates a growing preference for afloat repairs in time-sensitive commercial environments. Freight market volatility and narrow charter margins incentivize minimizing off-hire duration. When defects are minor and class-approved for underwater rectification, afloat repair provides a clear commercial advantage.

Time-sensitive operations such as:

- Propeller polishing to restore fuel efficiency
- Sea chest cleaning
- Localized underwater crack arrest
- Inspection following suspected grounding

are increasingly executed without docking, particularly when vessels cannot afford prolonged withdrawal.

This shift does not diminish the importance of dry docking but repositions it as a structurally strategic intervention rather than a universal solution. Afloat repairs serve as tactical responses within ongoing commercial operations.

However, the preference for afloat solutions must be balanced against long-term structural integrity. Temporary or partial repairs may generate deferred liabilities if not integrated into planned docking cycles.

Long-Term Lifecycle Cost Optimization

Lifecycle cost optimization requires integrating direct repair cost, indirect commercial exposure, fuel performance, and structural durability into a unified evaluation model.

Dry docking typically involves higher immediate expenditure but allows comprehensive renewal of coatings, steel structure, and propulsion components. High-performance antifouling systems and full surface preparation can significantly improve hydrodynamic efficiency and corrosion resistance.

Afloat repairs, while cost-efficient in the short term, must be evaluated within a long-term structural framework. Overreliance on temporary interventions may result in cumulative degradation, leading to a more extensive future docking scope.

The break-even modeling presented in this study demonstrates that economic preference shifts depending on:

- Severity of structural degradation
- Charter rate environment
- Remaining time before Special Survey
- Fuel cost levels

Thus, lifecycle optimization is dynamic rather than static.

Sustainability Considerations (Fuel Efficiency and Coating Performance)

Sustainability increasingly influences maintenance strategy. Hull condition directly affects fuel consumption and greenhouse gas emissions. Biofouling and coating degradation increase resistance, leading to higher bunker consumption and emissions intensity.

Afloat propeller polishing and selective cleaning offer rapid performance recovery, delivering measurable fuel savings shortly after execution. Conversely, full docking enables complete hull blasting and high-performance coating application, providing longer-term hydrodynamic benefits.

From an environmental compliance perspective, effective maintenance supports:

- EEXI and CII performance objectives
- Emission reduction strategies
- Extended asset service life

Sustainable fleet management, therefore, integrates repair timing with fuel efficiency strategy rather than viewing maintenance solely as defect correction.

11. Conclusion

This study has conducted a structured comparative evaluation of dry docking and afloat repairs within the operational context of Istanbul and the Turkish Straits region.

The findings confirm that **dry docking remains structurally indispensable** for major steel renewal, appendage removal, and statutory survey compliance. Its controlled environment and comprehensive access ensure permanent structural integrity and regulatory certainty.

Conversely, **afloat repairs provide significant operational flexibility**, particularly in time-sensitive commercial scenarios. Rapid mobilization, reduced deviation, and minimized off-hire exposure make underwater interventions economically attractive for minor or localized defects.

The research demonstrates that optimal repair strategy selection is conditional. It depends on:

- Damage scope and structural criticality
- Schedule pressure and charter exposure
- Regulatory survey requirements
- Yard congestion and slot availability
- Environmental and regional operational constraints

Within this decision environment, Istanbul offers a unique infrastructure model supporting both dry docking and afloat repair effectively. Its geographic position, combined with diversified repair capacity, enhances strategic maintenance flexibility for shipowners operating in the Black Sea–Mediterranean corridor.

Repair strategy is therefore not a binary choice but a context-sensitive allocation decision within a broader lifecycle management framework.

12. Practical Contribution

This study provides a structured decision framework designed to support evidence-based maintenance planning.

The framework assists:

Technical Managers

- In aligning repair method selection with structural requirements and class compliance
- In evaluating preparatory work sequencing to reduce docking duration
- In integrating underwater inspection data into scope planning

Fleet Superintendents

- In balancing off-hire exposure against structural integrity needs
- In coordinating docking schedules with trade cycles
- In assessing risk exposure in congested maritime regions

Shipowners

- In understanding total cost of repair beyond direct yard quotations
- In modeling break-even scenarios between dry docking and afloat alternatives
- In integrating sustainability considerations into maintenance strategy

By synthesizing operational feasibility, cost structure analysis, and scheduling impact within a unified framework, this research supports rational, data-driven repair strategy selection.

The practical value lies not only in comparative analysis but in providing a repeatable evaluation model adaptable to varying vessel types, charter environments, and regional operational conditions.

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